TREATMENT SYSTEMS FOR LIQUID SWINE MANURE USING POLYMERS AND BIOLOGICAL NUTRIENT REMOVAL

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ABSTRACT

In the USA, we evaluated in pilot studies the use of polyacrylamide (PAM) polymers to enhance separation of solids and liquid from liquid swine manure and the use of polymer immobilized nitrifying bacteria technology (PINBT) for effective ammonia (NH_4^+) removal. Separation efficiencies of about 90% total and volatile suspended solids were obtained for flushed swine manure containing 2.2 to 15.8 g TSS/L using PAM treatment applied at rates of 80 to 120 mg/L. The treated solids captured 80 to 85% of the organic N (210 to 1280 mg/L) and P (60 to 510 mg/L) contained in the liquid manure. Although nearly the entire organic N is removed with PAM treatment, an equal amount still remains in the soluble, ammonia fraction. Our results showed that biological removal of N can be greatly enhanced with the use of acclimated microorganisms immobilized in polymer pellets. Compared to conventional systems, the use of PINBT allows an increase of about 1,000-fold more nitrifying bacteria to be retained in the reaction tanks. Nitrification rates of 600 g N/m^3-tank/day and 90% NH_4^+ removal efficiency were consistently obtained treating swine wastewater containing 410 mg NH_4-N/L. We also evaluated the coupling of nitrification with denitrification treatment using a pre-denitrification flowsheet for the purposes of total N removal. Denitrification efficiencies > 95% were obtained using naturally available carbon source from liquid manure.

INTRODUCTION

Interest in finding alternative, functional, and affordable methods for nutrient management of confined animal production has greatly increased. Animal feeding operations in the USA are developing with a larger number of animals concentrated in fewer farms. Many areas in the USA are producing more manure nutrients than available cropland can absorb due to a net import of nutrients as feed. However, transport of this manure in a liquid form is not feasible. Thus, solids-liquid separation of untreated liquid manure and transport of the solids to nutrient deficient areas are critical for conserving nutrients and lessening the environmental impact of confined production systems (Vanotti and Hunt, 1999). When solids separation is combined with biological nutrient removal processes, there is the added benefit of total systems alternative to traditional anaerobic lagoon treatment. Although there are many existing technologies from the sewage industry that can be applied to solve animal waste problems, strategies for successful treatment of animal waste are distinctly different from municipal treatment. The strategy followed by the sewage industry is a combination of aeration and water clarification that enables discharge into a watercourse. Such complete treatment is unlikely to be appropriate for most farms (Burton, 1992). Nonetheless, adaptation of municipal technologies is likely to be the basis from whence the appropriate technologies for animal waste can emerge. The objectives of this paper are to describe research advances we have made in two such technologies addressing important aspects of animal waste treatment: enhanced solids-liquid separation using polymers and enhanced biological nitrogen treatment using immobilization technology.

SOLIDS-LIQUID SEPARATION TREATMENT

Separation of suspended solids from swine liquid manure using screens and presses is very inefficient (5 to 15%) and requires chemical coagulation to bind together the small particles of solids into larger clumps. Inorganic flocculants such as alum or calcium and iron salts are very effective, but they have limited application because of the large amounts of material needed (>1500 mg/L) and the large quantity of additional solids generated (Loehr, 1973; Westerman and Bicudo, 1998). Recent work on solids separation using organic polymers (Vanotti and Hunt, 1999) indicates that polyacrylamide (PAM) treatment not only is very effective for flocculating total suspended solids (TSS) and separating organic nutrients from swine wastewater, but it also has a very low chemical dose demand. Polyacrylamides are long chain, water-soluble polymer molecules that destabilize suspended, charged particles by adsorbing them and building bridges between several suspended particles, resulting in newer, larger particles (or flocs) that can be separated by physical processes. Evaluation of cationic, anionic, and neutral PAMs indicated that the cationic type is very effective for separating solids and nutrients from flushed swine wastewater (Vanotti and Hunt, 1999). Within the cationic PAMs, materials that had moderate-charge density (20%) were more effective than polymers with higher charge density.

Excellent separation efficiencies were also obtained in polymer trials in a feeder-to-finish operation in Bladen Co., North Carolina. Four houses with slatted floors containing 4800 pigs were flushed five times per day at a rate of 25 L/pig/day. Wastewater strength increased (from 5 to 25 g total solids/L) with the size of the pigs (18 to 109 kg) during the 16-wk evaluation period. Total suspended solids (TSS) and volatile suspended solids (VSS) removal efficiencies > 85% were obtained with PAM rates of 80 to 120 mg/L applied to samples containing 2.2 to 15.8 g TSS/L (Table 1). We found that it was more economical to remove solids and nutrients from higher strength wastewater. For example, the polymer usage rate for the more diluted wastewater (5 g TS/L) was > 4% (g polymer/100 g dry solids separated) while the usage rate obtained with the highest strength wastewater (25 g TS/L) was < 1%. The calculated chemical cost associated with a 1% polymer usage rate is about $1.40 per finished pig.

Table 1. Enhanced solids and nutrient separation from flushed swine manure using polyacrylamide (PAM) polymer.*

Flush Constituent	Separation by Screen (%)	Separation by Screen after PAM Flocculation (%)
Total Suspended Solids	15.4	89.5
Volatile Suspended Solids	15.0	89.2
Chemical Oxygen Demand	8.0	64.6
Organic N	13.2	80.0
Organic P	10.6	85.2

*Data is average of 5 trials during a 16-wk period.
Cationic PAM; optimum rate 80 to 120 mg/L (avg. 100 mg/L); 1-mm screen used.
Initial concentrations: TSS = 2.2 to15.8 g/L, VSS = 1.7 to 12.6 g/L, COD = 6 to 31.3 g/L, organic N = 210 to 1280 mg/L, and org. P = 60 to 510 mg/L.

Organic nutrient and COD concentrations in the treated effluent were also significantly decreased with PAM treatment (Table 1). The concentration of total P in the flushes varied from 110 to 590 mg/L; approximately 85% were organic forms and the rest soluble phosphates. For nitrogen, TKN concentration ranged from 890 to 2440 mg/L, with about 45% organic N and 55% ammonia N. The organic nutrients were efficiently separated by PAM flocculation: 80 and 85% removal for N and P, respectively. Inorganic N and P fractions in the liquid effluent were not decreased with PAM treatment, which was expected since PAM function is to group fine particulate matter. Separation of organic N and P followed a 1:1 relationship with TSS capture by PAM. On the average, 7.25 g of N and 3.3 g of P were removed from the liquid phase for every 100 g of dry TSS separated by PAM treatment.

After the initial separation of liquids and solids, additional separation is necessary before effective and economical transport can be accomplished. We are currently evaluating the potential of the Deskins Quick-Dry Filter Bed (Deskins Co., Alexandria, Indiana, USA) for dewatering liquid swine manure. Deskins' system uses an in-line polymer preparation and flocculator system, which eliminates the need for batching tanks, mixers, and polymer transfer pumps. Surface and subsurface bed stabilization is provided with a "Quick-Dry" plastic media that eliminates compaction of the sand and improves drainage environment. The pilot unit included two filter beds (20 x 16 ft) for operation on an alternate basis, receiving 30 cm of flushed swine manure during each drying cycle. The beds were constructed with several layers of media starting with a 45-cm layer of washed stone (1.9-cm size) at the bottom, then a 15-cm middle layer of pea gravel (0.95-cm size) and plastic media, and finished with 15 cm of coarse sand (0.5-mm size) on top. Initial testing of the Deskins system (April 2000) showed excellent treatment performance producing a transparent effluent and the following removal efficiencies: 93% for TSS; 92% for VSS; 88% for BOD_5; and 80% for organic N and P. The system produced removable cakes in 4 to 6 hours and reached manure solids content of 48% in 20 hours.

NITRIFICATION TREATMENT

Although nearly the entire organic N is removed with the suspended solids, a similar amount still remains in the soluble, ammonia fraction. Thus, after the solids are removed, the wastewater must be treated to capture and/or transform the nutrients in the soluble fraction. One of the primary transformations is the conversion of ammonia nitrogen to nitrate nitrogen via microbial nitrification. Biological removal of N through the process of nitrification and denitrification is regarded as the most efficient and economically feasible method available for removal of N from wastewaters (Tchobanoglous and Burton, 1991). In this biological nitrogen removal process, the occurrence of complete nitrification is a minimum requisite. With wastes rich in carbonaceous materials such as swine wastewater, the nitrifying bacteria compete poorly with heterotrophic microorganisms. Nitrifiers need oxygen, lower carbon, a surface area, and a growth phase before sufficient numbers are present for effective nitrification. Results from several studies on nitrification of liquid swine manure (Ballester et al., 1992; Blouin et al., 1990; St.-Arnaud et al., 1991) have consistently shown the need for massive inoculation of nitrifying bacteria in order to attain rapid ammonia conversion and minimize losses via volatilization because of the extremely low concentration of nitrifiers in these wastes.

High nitrification rates are also feasible with polymer-immobilized nitrifying bacteria technology (PINBT). Through the immobilization process, the microorganisms are provided with a very suitable environment to perform at optimal effectiveness. The nitrifiers are entrapped in 3- to 5-mm pellets made of polymers that are permeable to NH_3, oxygen, and carbon dioxide needed by these microorganisms. The successful application of this technology has been demonstrated for municipal wastewater in several full-scale plants in Japan [Pegasus process, Takeshima et al. (1993)]. Tanaka et al. (1991) reported nitrification rates of municipal wastewater that were three times higher than those of the conventional activated sludge process. Typical materials are polyethylene glycol (PEG) and polyvinyl alcohol (PVA). Pellets made of synthetic polymers are superior to natural polymers in terms of strength and durability; their estimated life span is about 10 years. Vanotti and Hunt (1998 & 2000) reported that this technology can be adapted for fast and efficient removal of NH_4^+ contained in anaerobic lagoons by using acclimated microorganisms. Nitrifying bacteria were cultivated in a medium containing 300 mg NH_4^+ N/L, immobilized in PVA polymer pellets, and then used for nitrification of swine lagoon wastewater containing ~230 mg NH_4^+ N/L. Nitrification efficiencies of more than 90% were successfully obtained even at a short hydraulic retention time (HRT) of 12 h. High-ammonia nitrifiers were also successfully developed and immobilized in polymer pellets and used to treat swine wastewater containing 350 to 2600 mg N/L (Vanotti et al., 1999b). Ammonia removal rates of 915 to 990 mg N/L-reactor/day and 97 to 100% nitrification efficiency were obtained in batch treatment with no inhibition to these high NH_3 concentration wastes.

We conducted a pilot experiment in Duplin Co., NC, to remove ammonia from swine wastewater using PINBT (Vanotti et al., 1999a). The unit was modeled after the Pegasus process (Takeshima et al., 1993) used in Japanese municipal plants and contained PEG pellets manufactured by the Hitachi Plant Engineering & Construction Co., Tokyo, Japan. The unit consisted of a 0.34-m^3 contact aeration tank used to lower influent BOD, a 0.18-m^3 sedimentation tank, and a 1.3-m^3 aerated fluidized tank used for nitrification treatment. The unit was instrumented with pH and DO controllers. PEG pellets initially containing 2% activated municipal sludge were added to the nitrification tank at 10% (v/v) concentration. Pellets were successfully acclimated to swine wastewater during the first 3-month period in which the ammonia-loading rate was increased by decreasing the hydraulic residence time (HRT).

Table 2. Water quality of treated swine wastewater obtained with a Pegasus immobilized biomass nitrifying reactor.*

	Influent Quality	Treated Effluent
pH	8.14	7.67
Alkalinity, mg/L	1,931	333
Suspended Solids, mg/L	460	205
COD, mg/L	898	517
BOD_5, mg/L	210	79
NH_4-N, mg/L	410	40
NO_3-N, mg/L	0	396
Kjeldahl-N, mg/L	494	88
Total N, mg/L	494	482

*Average process data for June 1998; continuous flow with HRT = 16 hours; NH_4-N Load = 615 g N/m^3 tank/day. Nitrification tank contained 10% PEG pellets. Pilot plant in Duplin Co., North Carolina.

The pellets showed excellent performance; the capacity for ammonia removal from swine wastewater exceeded design expectations based on municipal systems (Table 2). Ammonia removal rates up to 650 g N/m^3-tank/day were consistently obtained during summer months and a hydraulic residence time of 12 h. All the ammonia-N removed was nitrified without losses of N by volatilization. The nitrification activity of the pellets remained high during the 3-year continuous evaluation period (1997-2000).

NITRIFICATION / DENITRIFICATION TREATMENT

Biological denitrification processes can be coupled to a nitrification reactor so that total nitrogen removal is achieved. Because bacteria responsible for biological denitrification under anoxic conditions are heterotrophic, they need a suitable source of organic carbon as an energy source. In wastewater treatment, two main types of organic carbon source can be used: either an endogenous source contained in the wastewater or an external source like methanol, ethanol, etc. In the first case, the process leads to a pre-denitrification flowsheet that recycles a part of the nitrified effluent to an anoxic tank; in the second case, it leads to a post-denitrification configuration. The advantage of the pre-denitrification configuration for the purposes of total N removal is that it uses a naturally available source from wastewater without the need to add any complementary chemicals (Chudoba et al., 1998). Thus, denitrification removes both NO_3^- and organic loads to the nitrification tank. A system that uses a pre-denitrification configuration coupled to a PINBT reactor (Biogreen process) is described here. A pilot plant is currently under investigation at Lake Wheeler Rd. farm at Raleigh, North Carolina. It uses the PAM separated manure effluent from a Deskins bed.

Table 3. Water quality of treated swine wastewater obtained with a Biogreen nitrification/denitrification system.*

	Influent Quality	Treated Effluent
pH	7.38	7.53
Alkalinity, mg/L	1,345	630
Suspended Solids, mg/L	423	373
COD, mg/L	1,003	653
BOD_5, mg/L	237	90
NH_4-N, mg/L	143	3
NO_3-N, mg/L	0	8
Kjeldahl-N, mg/L	290	36
Total N	290	44

*Process data for May 2000; continuous flow with HRT = 13 h for nitrification tank and 31 h for denitrification tank; TKN load = 527 g N/m^3 nit. tank/day. Nitrification tank contained 18% PEG pellets. Pilot plant evaluation in Raleigh, North Carolina.

The basic Biogreen pilot unit was designed to treat 1 m^3/day and contains a 1.3-m^3 anoxic denitrification tank to remove BOD and NO_3-N followed by a 0.55-m^3 nitrification tank containing 100 L of PEG pellets for conversion of NH_4^+ to NO_3^- and a 0.63-m^3 settling tank for precipitation of SS. Pumps recirculate the nitrified effluent and the settled sludge into the anoxic tank for denitrification. The unit is completed with pH and ORP controllers and monitoring and sampling equipment. Performance data of this system are shown in Table 3. Nitrogen removal efficiencies of 88% for TKN and 98% for NH_4^+ and denitrification efficiencies of 97% were obtained using a 1 m^3/d load, a recirculation rate of 7.5 for nitrified liquid and 1.5 for settled sludge.

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